Platte River Basin Water Plan Update
Groundwater Study Level I (2009 - 2013)

Available Groundwater Determination
Technical Memorandum

Executive Summary

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INTRODUCTION

Between 2001 and 2006 the Wyoming Water Development Commission (WWDC) completed individual water plans for each of Wyoming's seven major river basins. The last water plan completed during that period, for the Platte River Basin (Trihydro Corporation and others, 2006) included an available groundwater determination in Technical Memorandum 3.3 (Lidstone and Associates, 2005). The 2013 Available Groundwater Determination presented in this report updates and expands the previous technical memorandum with a new compilation of information and represents the most current assessment of the groundwater resources of the Platte River Basin. This technical memorandum has the following objectives:

- Identify the major (most widely used) aquifers in the Platte River Basin.
- Define the three-dimensional extent of the aquifers.
- Describe the physical characteristics, water chemistry and potential contaminants of the aquifers and confining (hydrogeologic) units.
- Estimate the quantity of water in the aquifers.
- Describe the aquifer recharge areas.
- Estimate aquifer recharge rates.
- Estimate the "safe yield" potential of the aquifers and describe implications of hydrologically connected groundwater and surface water.
- Describe and evaluate existing groundwater studies and models.
- Identify future groundwater development opportunities to satisfy projected agricultural, municipal and industrial demands.

PLATTE RIVER BASIN DESCRIPTION

This report examines groundwater resources in that portion of the North Platte River Basin located within Wyoming as well as the small upstream areas in Nebraska and Colorado that flow into Wyoming. Additionally, this report includes groundwater resources in the Wyoming headwater drainages of the South Platte River. The Platte River is the major tributary to the Missouri-Mississippi River Basin. Primary Wyoming tributaries to the North Platte River include the Laramie, Medicine Bow and Sweetwater rivers. Crow Creek and Lodgepole Creek are Wyoming headwater tributaries to the South Platte River. The hydrologic divides of these drainages define the limits of the Platte River Basin study area.

The Platte River Basin drainage basin covers approximately one quarter of the state in southeastern and central Wyoming, plus smaller areas of northern Colorado and western Nebraska. The basin comprises 24,106 square miles (15.43 million acres) in Wyoming, 2,074 square miles (1.33 million acres) in Colorado, and 109 square miles (0.07 million acres) in Nebraska. In Wyoming, the Platte River Basin includes all of Albany, Laramie and Platte counties, parts of Goshen, Carbon, Natrona, Converse and Fremont counties, as well as small, undeveloped areas of southwestern Niobrara, western Sublette, and northern Sweetwater counties. In Colorado, the basin covers all of Jackson County, parts of Larimer County and a small area of northern Weld County. The basin also includes small areas of Scottsbluff and Sioux counties in Nebraska (Figure 1).

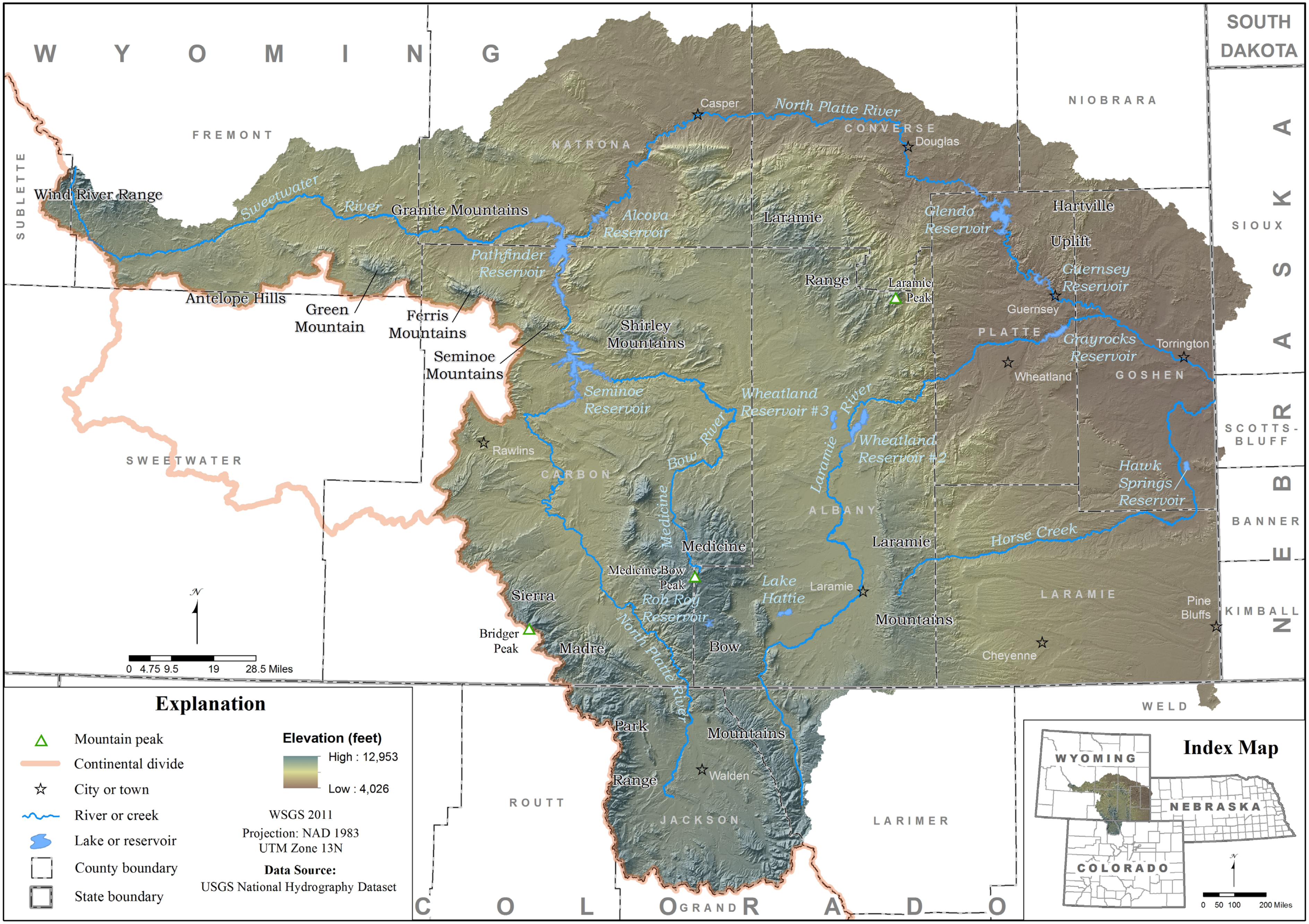

Figure 1. Major structural and physiographic features, drainages, and bodies of water, Platte River Basin.

The Platte River Basin in Wyoming serves as home to approximately 231,000 people or about 41 percent of the state's current population (2010 census). The basin contains the state's three largest incorporated municipalities (Cheyenne, Casper and Laramie), several larger towns such as Rawlins, Douglas, and Wheatland, numerous smaller towns and a substantial rural population.

The landscape of the Platte River Basin consists of several mountain ranges of the southern Rocky Mountains, valleys, rolling plains, plateaus, escarpments, bluffs, hills, drainage ways and structural basins. Elevations in the Platte River Basin range from 4,025 feet above mean sea level at the North Platte River where it crosses the Wyoming-Nebraska state line, to 12,013 feet at Medicine Bow Peak (Trihydro Corporation and others, 2006).

Climate types in the Platte River Basin range from semi-arid continental within structural basin interiors to humid-alpine in the bordering mountain ranges. The mountain ranges capture much of the atmospheric moisture through orographic uplift that results in increased annual precipitation in the mountainous regions while substantially decreasing precipitation in the basin interiors. Air temperatures vary seasonally from well below 0° F in the winter to more than 100° F in the summer. Most precipitation within the basin occurs as snowfall during the winter and early spring and as convective thunderstorms during late spring and summer months (Libra and others, 1981). Average annual precipitation ranges from 9 to 15 inches in the interior basin areas and plains east of the Laramie Mountains; 16 to 30 inches along the foothills adjacent to the mountains, over the lower uplifts, and the high plains around Horse Creek; and 31 to 60 inches in the higher mountain ranges.

Land use in the Platte River Basin is influenced by elevation, climate, the distribution of surface water, precipitation and the location of mineral resources. In the high mountain areas above timberline, the alpine lands are generally used only for recreational purposes. At lower elevations, thickly forested areas are utilized for recreation and limited logging. Grazing is the dominant use on rangelands, foothills and riparian areas. Agriculture plays a significant role in the basin; approximately 4.1 percent (632,630 acres) of its surface area consists of irrigated cropland (WWC Engineering, Inc. and others, 2007).

PLATTE RIVER BASIN GEOLOGY

The Platte River Basin is composed of asymmetric intermontane structural basins formed during the Laramide orogeny (Late Cretaceous-Eocene) that contain up to 35,000 feet (Richter, 1981) of Cenozoic, Mesozoic and Paleozoic sediments deposited on Precambrian crystalline basement rocks (Libra et al., 1981; Richter, 1981). The structural basins are bordered by compressional uplifts cored by Precambrian granite and mantled by moderately to steeply dipping sedimentary formations (Libra et al., 1981). Paleozoic and Mesozoic formations exposed along the flanks of the mountain ranges surrounding the Platte River Basin were folded, faulted and eroded from the highest areas of the uplifts during the Laramide Orogeny; they now dip basinward at angles ranging from approximately 5 degrees to vertical, and some are overturned. Strata of Paleocene through early Eocene age are also deformed around the perimeters of these structural basins but are mostly flat lying in the interior basin areas. Numerous anticlinal structures with associated faults formed during the Laramide Orogeny crop out along the margins of the structural basins.

The major Laramide structural elements of the Platte River Basin include:

- The folded and faulted Precambrian basement
- The Denver, Laramie, Hanna-Carbon, Shirley, Wind River and Powder River basins
- The mountain ranges and uplifts that surround and separate the basins:
    - The Laramie, Medicine Bow and Sierra Madre/Park mountain ranges

- Green Mountain, Ferris Mountains, Seminole, and Shirley Mountains
- The Granite Mountains
- The Casper Arch and Hartville Uplift
- The Rawlins Uplift
- The Wind River Range

Mineral resources
Significant quantities of oil and gas have been developed in the Casper Arch, High Plains and northern Great Divide Basin. Recently, increased oil and gas exploration and production operations are focused on the Cretaceous Niobrara and Frontier formations from Cheyenne north to Douglas. Uranium and coal resources have been commercially developed in the Platte River Basin. Currently, there is no active coal mining in the basin but uranium is mined by in-situ recovery extraction northwest of Douglas. Industrial minerals including sand, gravel, clay, limestone, dolomite, feldspar, shale, bentonite and gypsum are still extensively mined within the Platte River Basin.

The Wyoming State Geologic Survey (WSGS) has evaluated many Platte River Basin sites for potential development of precious metals, gemstones, base metals, industrial minerals, decorative stones, coal, coal bed natural gas and oil and gas. Future development of these minerals could impact groundwater resources.

BASIN HYDROGEOLOGY

Groundwater circulation, availability and development
Groundwater circulation in the Platte River Basin is controlled primarily by the Laramide structural basins and associated geologic structures. Huntoon (1993) presented a summarized conceptual model, "The Influence of Laramide Foreland Structure on Modern Ground-water Circulation in Wyoming Artesian Basins," that he and several of his graduate students at the University of Wyoming developed over several years of research and field work, largely within the Bighorn and Platte River basins. The central thesis of their research is that large-displacement thrust faults, reverse-fault-cored anticlines and associated fractures and anisotropic permeability that developed during Laramide compressional deformation strongly influence groundwater recharge and circulation through the major Paleozoic and lower Mesozoic major carbonate aquifers exposed along the major uplifts of the Wyoming foreland basins. The main components of this conceptual model that pertain to groundwater development include:

- The Wyoming foreland mountain ranges consist of large-scale uplifts situated atop large-displacement (thousands of feet) basement thrust faults with fault-severed strata on one side and homoclinal dipping strata on the other.
- The compressional processes that shaped the Wyoming foreland mountain ranges and associated structural basins during the Laramide orogeny also produced smaller structures such as reverse- and thrust-cored asymmetric anticlines within the basins.
- Groundwater circulation is not only controlled by the Laramide structures, but also alters the hydrogeology of them.
- Karst developed along pre-existing fractures within the major carbonate aquifers during erosion and exposure of the recharge areas, and ongoing karstification have greatly enhanced the permeability of these aquifers around the perimeters of Wyoming's Laramide basins.
- Groundwater circulation is primarily parallel to bedding. Vertical circulation within the deep artesian basins

is very limited except along faulted and fractured anticlines where the permeability of confining units is enhanced.

- Large production from the major carbonate aquifers is limited to local areas of large solution-enhanced permeability (modern karstification) developed within and down gradient of recharge areas along homoclinal (not fault-severed) flanks of the Laramide uplifts where these aquifers are exposed.

- Groundwater in the major carbonate aquifers at homoclinal basin margins is generally of good quality, and high yields can be obtained under the right conditions.

- The synclinal areas of folds and the footwall sides of fault-severed aquifers are not good prospects for groundwater development.

The conceptual model described above has been utilized in groundwater development projects throughout the state. Appendix B lists Wyoming Water Development projects that have implemented this exploration model.

The Wyoming Statewide Framework Water Plan (WWC Engineering, Inc. and others, 2007) classified the Platte River Basin geologic units as follows:

Major Alluvial Aquifers - Quaternary alluvium

Major Sandstone Aquifers - Wasatch, Wind River, Fort Union, Lance, Fox Hills and Cloverly/Dakota formations

Major Limestone Aquifers - Casper, Minnelusa, and Hartville formations; Madison Limestone; Bighorn Dolomite

Minor Aquifer - Quaternary non-alluvial deposits; Arikaree, Frontier, Gallatin, and Gros Ventre formations; Mesaverde Group; Flathead Sandstone

Marginal Aquifers - White River and Sundance formations

Major Aquitard (Confining Unit) - Lewis, Cody, Pierre, Steele, Baxter, Carlisle, Thermopolis, Mowry, and Aspen Shale units; Meeteetse, Niobrara, Chugwater and Goose Egg formations; Precambrian rocks

Natural groundwater quality and hydrogeochemistry

For this report, groundwater-quality data were gathered from the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2010a), the USGS Produced Waters Database (PWD) (U.S. Geological Survey, 2010b), the Wyoming Oil and Gas Conservation Commission (WOGCC) database (Wyoming Oil and Gas Conservation Commission, 2010), the University of Wyoming Water Resources Data System (WRDS) database, and other sources such as consultant reports prepared in relation to development of public water supplies.

Groundwater quality in the Platte River Basin varies widely, even within a single hydrogeologic unit. Water quality in any given hydrogeologic unit tends to be better near outcrop areas where recharge occurs, and tends to deteriorate as the distance from these areas increases (and residence time increases). Correspondingly, the water quality in a given hydrogeologic unit generally deteriorates with depth.

The report contains statistical analyses and trilinear diagrams of groundwater quality for both “environmental water” and for “produced water” samples. Environmental water samples are from wells of all types except those used for resource extraction (primarily oil and gas production) or those used to monitor areas with known groundwater contamination. Produced-water samples are from wells related to natural resource exploration and extraction (primarily oil and gas production). Physical characteristics, major-ion chemistry, nutrients, trace elements and radiochemicals are summarized for both environmental and produced waters in Appendices E, F, G and H.

Aquifer sensitivity and potential sources of groundwater contamination
This report uses Geographic Information Systems (GIS) analysis of aquifer sensitivity (Hamerlinck and Arneson, 1998) to evaluate potential contamination threats to groundwater resources in the Platte River Basin. Potential contaminant sites were identified from Wyoming environmental regulatory agency databases and include facilities that handle substantial volumes of substances that released to the environment could migrate to the water table. These facilities are generally located in and near municipal, manufacturing and mineral resource areas in the basin.

Estimated recharge in the Platte River Basin
The hydrogeologic units in the Platte River Basin range in geologic age from Quaternary to Precambrian and are variably permeable. The basin's complex geology does not permit the use of the general assumptions regarding aquifer geometry, saturated thickness and hydraulic properties commonly employed by hydrogeologists in other settings that would be required to calculate a plausible estimate of total and producible groundwater resources. In this report, groundwater resources are evaluated by using previous GIS based estimates of average annual recharge (Hamerlinck and Arneson, 1998) to the outcrop zones of the basin's identified aquifers. Aquifer recharge zones, based on geologic age were generated as GIS shapefiles; these are: 1) Quaternary, 2) Lower Tertiary, 3) Upper Tertiary, 4) Mesozoic, 5) Paleozoic and 6) Precambrian aquifers. Total recharge volume for each aquifer recharge zone was calculated as the cell-by-cell product of the surface area within each aquifer recharge zone by the estimated average annual recharge.

Total average annual precipitation in the Platte River Basin for the 1981-2010 period of record was estimated as 19,677,600 acre-feet; the best estimate of average annual recharge to the Platte River Basin's sedimentary aquifers is 1,044,700 acre-feet per year.

REGULATORY CONSTRAINTS TO GROUNDWATER DEVELOPMENT – THE MODIFIED NORTH PLATTE DECREE AND THE PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

In the Platte River Basin there are significant judicial and regulatory constraints on the development of groundwater pursuant to the "Modified North Platte Decree" and the "Platte River Recovery Implementation Program."

In 2001 the Modified North Platte Decree between the states of Wyoming and Nebraska resolved decades of litigation over the water resources of the North Platte River Basin. In specific areas of the Platte River Basin, the Modified North Platte Decree restricts Wyoming diversions of groundwater with priority dates later than 1945 that are hydrologically connected to surface water. Criteria were developed under the North Platte Decree for identifying areas where groundwater is hydrologically connected. Based on these criteria, the SEO developed maps for the Modified North Platte Decree Committee that designate areas where groundwater is considered to be not hydrologically connected to surface water under Decree criteria..

In 1997, the states of Wyoming, Colorado and Nebraska, and the U.S. Department of the Interior developed the Platte River Recovery Implementation Program (PRRIP) to address several issues under the Endangered Species Act (ESA) related to the current use and future development of Platte River Basin water resources. The PRRIP has two primary objectives:

1. To maintain, improve and conserve water-dependent habitat on behalf of four threatened and endangered species, with populations located along the Platte River in central Nebraska.
2. To allow current use and future development of water resources in the Platte River Basin to proceed without additional ESA requirements related to these threatened and endangered species.

Because the depletion of surface water resources through the use of hydrologically connected groundwater would impact habitats of concern, the parties to the PRRIP adopted the hydrological connection criteria from the North Platte Decree.

GROUNDWATER USES AND BASIN-WIDE WATER BALANCE

Chapter 8 contains a discussion of current groundwater uses in the Platte River Basin. Thirty four maps (Figures 8-1 through 8-34) were prepared for this study to illustrate the geospatial distribution of groundwater permits according to use in the Platte River Basin. Only permits for wells that were likely to have been drilled (including abandoned wells) are included on the maps. Figures are provided for irrigation, stock watering, municipal, industrial, monitoring and miscellaneous permits. Groundwater permits are mapped relative to their date of issue (before or after January 1, 2005) on Platte River Basin scale maps and by total well depths on subregion scale figures. In order to provide better resolution of location in areas where permit density is high, permits for domestic, livestock, and groundwater monitoring were posted to a hydrogeologic base map prepared for each of seven groundwater subregions. The figures indicate the following trends for groundwater permits by use:

- Most **irrigation** permits appropriate water from wells located near the North Platte River, likely targeting alluvial deposits adjacent to the river. A substantial number of wells in the eastern part of the basin are located away from major drainages and directly withdraw water from the High Plains aquifer.

- **Livestock wells** are located throughout the Platte River Basin with some higher areas of concentration along rivers and other surface drainages within the interior basins. Many livestock wells are completed at relatively shallow depths within virtually all hydrogeologic units, including confining units, indicating that useful quantities of relatively shallow groundwater can be found at most locations within the basin.

- **Municipal wells** are located within or close to the municipalities that they supply and produce water from both bedrock and alluvial aquifers.

- Most **domestic wells** are located in rural areas, generally outlying population centers along surface drainages. Most wells are completed in Quaternary and Tertiary geologic units; however, domestic-use wells have also been permitted over a wide range of depths within virtually all hydrogeologic units, including confining units.

- **Industrial wells** are generally clustered in rural areas around conventional oil and gas fields, mining operations, and population centers.

- **Monitoring wells** are generally located near population centers, areas with industrial facilities, and along rivers and other large surface drainages, where facilities that require groundwater monitoring are concentrated.

- **Miscellaneous-use** and **test wells** are located throughout the basin in population centers, in mineral development areas, rural areas, and generally along rivers and larger surface drainages.

Chapter 8 (Table 8-2a) also contains a basin-wide water balance based on the mass balance equation:

Evapotranspiration = precipitation - surface water outflows - consumptive uses - estimated recharge
For this analysis, geospatial precipitation data was obtained from PRISM Climate Group (PRISM, 2012) for the Platte River Basin. The USGS Daily Streamflow Website http://waterdata.usgs.gov/nwis/rt as accessed for surface water outflow data. Consumptive use estimates for irrigation and stock watering, industry, municipal and domestic and recreational and environmental uses were obtained from Harvey Economics (2005) and the Wyoming Oil and Gas Conservation Commission (2012). Finally the water budget analysis used the annual recharge estimate

calculated in Chapter 6 of this report. The results of the water balance analysis, shown in Table 1, indicate that evapotranspiration (ET) accounts for about 85 percent of precipitation losses in the basin; the USGS estimate places ET losses at 86 percent of precipitation. Current estimated consumptive uses of surface water and groundwater constitute about 6 percent of annual precipitation.

Table 1. Summary water balance statistics.

Water balance statistics	Volume (ac-feet)
[1]Average annual Platte River Basin precipitation (1981 - 2010)	19,677,577
Annual precipitation remaining after subtracting surface water outflows from basin outflows.	18,865,638
[2]Total consumptive use - surface water and groundwater (average of normal and high water demand years)	1,131,449
Water available to recharge & evapotranspiration	17,734,189
[3]Calculated total recharge volume to sedimentary aquifers	1,044,651
Remaining precipitation lost to evapotranspiration	16,689,538
Comparative estimate	
Estimation of evapotranspiration in the Platte River Basin using the USGS regression[4] with climate and land-cover data.	16,944,718

[1]PRISM, 2012

[2] Harvey Economics, 2005

[3] Table 6-2

[4]Sanford and Selnick, 2013

FUTURE WATER DEVELOPMENT OPPORTUNITIES

Future groundwater development projects in the Platte River Basin are largely affected by the issues of water availability, funding, stakeholder involvement, water quality, environmental regulation and, perhaps most importantly, the court decrees and interstate agreements regulating the appropriation of water.

Within the context of these issues, Trihydro Corporation (2007) conducted the North Platte River Groundwater Assessment Study (NPRGAS) for WWDC during 2002 - 2004 (revised 2007) to identify groundwater resources that were determined to be "non-hydrologically connected" to the surface waters of the North Platte River. Specifically, the basin wide groundwater evaluation sought to identify high yield aquifers that could produce 500 to 1,000 gallons per minute (gpm) per constructed well. Initially, 73 groundwater prospects were identified in the Platte River Basin. Subsequent joint evaluations by Trihydro, Lidstone, the SEO, WWDC and the Wyoming Attorney General's Office reduced the list of prospects to 10. Table 2 summarizes the general potential for development of the state's major aquifers, grouped by geologic age.

Table 2. Generalized groundwater development potential for major regional aquifer systems in the Platte River Basin (modified from Trihydro Corporation, 2007b).

Age	System	Location	Well yields	Major aquifers	General potential for new development
Quaternary	Alluvial	Throughout Platte River Basin	Moderate to large	Unconsolidated deposits	Poor – Hydrologically connected
	Non-alluvial	Throughout Platte River Basin	Moderate to large	Primarily unconsolidated terrace deposits	Poor – Likely to be hydrologically connected
Tertiary	Late	Within and along margins of structural basins	Moderate to large	Ogallala, Arikaree, White River, Moonstone, Split Rock, Browns Park	Poor– Groundwater control areas in eastern basin. Very good in Split Rock formation.
	Early	Within and along margins of structural basins	Small to large	Wasatch and Fort Union and equivalents	Fair
Mesozoic	Late Cretaceous	Structural basins	Small to large	Ferris, Lance, Fox Hills, Medicine Bow, Mesaverde, Frontier	Fair to good
	Early Cretaceous	Structural basins - limited surface exposures	Small to moderate	Muddy Sandstone, Cloverly, Inyan Kara	Fair – insufficient yields and marginal water quality.
	Triassic Jurassic	Structural basins - limited surface exposures	Small to moderate	Nugget Sandstone Sundance	Fair – insufficient yields and marginal water quality.
Paleozoic	Late	Exposed on flanks of uplifts	Small to large	Casper, Madison, Amsden, Hartville, Tensleep,	Very good.
	Early	Largely absent in Platte River Basin	Unknown	Englewood, Fremont Canyon, Bighorn, Buck Spring, Flathead Sandstone	Poor - largely absent.
Precambrian	Precambrian	Structural uplifts	Small to moderate	Undifferentiated	Poor – insufficient yields

CURRENT WWDC GROUNDWATER DEVELOPMENT PROSPECTS

As of November 2012, the Wyoming Water Development Commission (WWDC) had several projects in progress within the Platte River Basin of Wyoming. These projects include:

- A new Arikaree Formation water supply well was constructed for the Town of Burns (Laramie County) and located to the northwest of the town.
- An irrigation well was constructed in Quaternary terrace gravel deposits in the northwestern part of the City of Torrington (Goshen County) to replace an older irrigation well that had a pump stuck in the well and well casing problems.

Some WWDC projects that may occur in the near future in the Platte River Basin include:

- A construction project for the City of Douglas (Converse County) that will make improvements to the spring box used for their municipal water supply.
- A possible test well to be constructed into the Fox Hills Sandstone for the community of Hawk Springs (Goshen County).

- A replacement water supply well offsetting an existing water supply well for the Town of Guernsey (Platte County).

- A possible test well for the community of Jeffrey City (Fremont County).

In addition to the WWDC projects in the Platte River Basin, the U.S. Geological Survey (USGS) commenced in November 2012 with the drilling of a series of approximately three (3) nested test wells located to the south of the Town of Pine Bluffs (Laramie County). At least one of these USGS wells is planned to fully penetrate the High Plains aquifer (Ogallala Formation, Arikaree Formation and White River Group) and continue penetration through the Lance Formation, Fox Hills Sandstone, and stop drilling in the top of the Pierre Shale. The USGS will lithologically and geophysically log these wells and collect core samples through these formations. Information collected from these test wells will be available from the USGS Wyoming Water Science Center located in Cheyenne, Wyoming.

SUMMARY

This study evaluated available groundwater resources in the Platte River Basin of Wyoming and small upstream watersheds in Colorado and Nebraska. The potential for future groundwater development in the basin is fair to very good in late Tertiary through early Paleozoic aquifers. New development projects will need to be sited and designed in compliance with the provisions of the Modified North Platte Decree and the Platte River Recovery Implementation Program.

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